Detection and Retrieval of Mineral Dust Aerosol using AERI During the UAE² Field Campaign

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I. Introduction

- How to best characterize dust optical and microphysical properties especially in the IR remains to be an open-ended question in today's dust science community mostly due to lack of observations and measurement uncertainties (Reid J. et al. 2003)[1].
- These large uncertainties in key dust properties makes it impossible to quantify the magnitude of radiative forcing. Even the sign of forcing at the TOA is unclear (Sokolik et al. 2001)[2].
- What's needed are comprehensive measurements of dust properties in regions heavily impacted by dust such as the Gobi and Saharan Deserts, and the Arabian Gulf.
- To further our understanding of the Arabian Gulf region the United Arab Emirates Unified Aerosol Experiment (UAE²) was conducted from Aug-Oct 2004.
  - 2 major surface sites (Fig. 1a) were deployed to UAE during UAE² to help improve our understanding of dust.
  - NRL Mobile Atmospheric Aerosol and Radiation Characterization Observatory (MAARCO) performed radiation measurements and collected aerosol in-situ data on the coast.
  - GSFC NASA Surface Measurements for Atmospheric Radiation Transfer (SMART) (Fig. 1b) was ~160km inland inside the UAE interior at Al Ain Airport. SMART consists of an array of remote sensing equipment including the AERI instrument (Fig. 1c).

❖ This study….

i. **uses in-situ data to build an IR dust optical properties database**
ii. **retrieves dust optical/microphysical properties using AERI radiances**
iii. **uses a collocated AERONET sun-photometer for optical depth comparisons**
iv. **investigates mineralogy retrievals using AERI radiances**

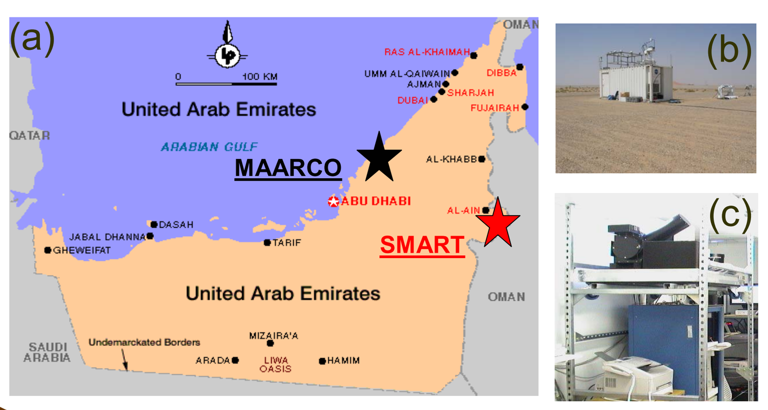

Fig. 1a. UAE map showing locations of both surface sites.
Fig. 1b. SMART trailer at Al Ain Airport
Fig. 1c. AERI instrument inside SMART

I I. Summary of AERI Observations

- AERI collected 20 days of data from Aug-Sept under mostly hazy and dusty conditions with an occasional mix of low clouds and cirrus
- A low-level inversion contained dust within 2-3 km of the surface
  - Fig. 2(a) shows AERI brightness temperature (ΔBT) spectra for background dust (1-3) just before dust front arrives. ΔBT means a minimum reference spectra ($\tau_{0.55\mu m}$) is subtracted to remove water vapor effects.
- Fig. 2(b) is summary plot of daily averaged ΔBT (z-axis) in the 800-1200 cm^{-1} region for Sept 2004.
  - Time (x-axis) is given in days and wavelength (y-axis) is expressed in wave numbers.Yellow dots denote wavenumber regions (narrow spectral channels) having minimum brightness temperatures.
  - Water vapor corrections are applied and clouds removed using collocated MPL at SMART
  - Note variability in slopes between designated wavenumber regions indicative of changing dust optical/microphysical properties

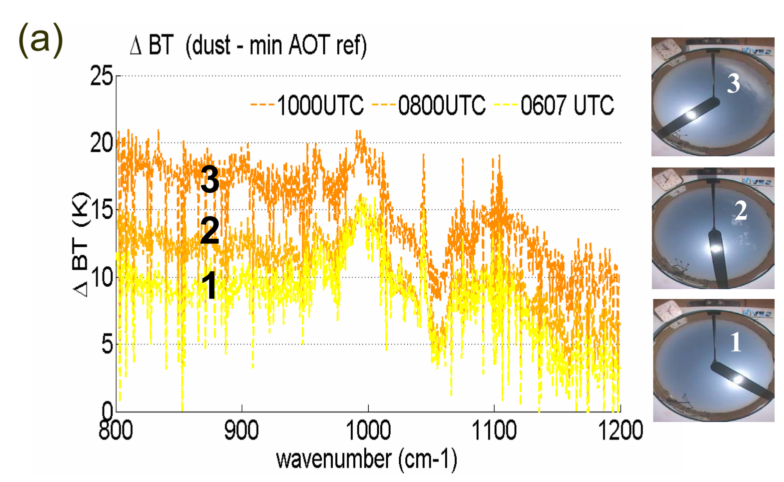

Fig. 2a. AERI ΔBT spectra on Sept 22[nd]. corresponding to increased dust loading (1-3) just before dust event

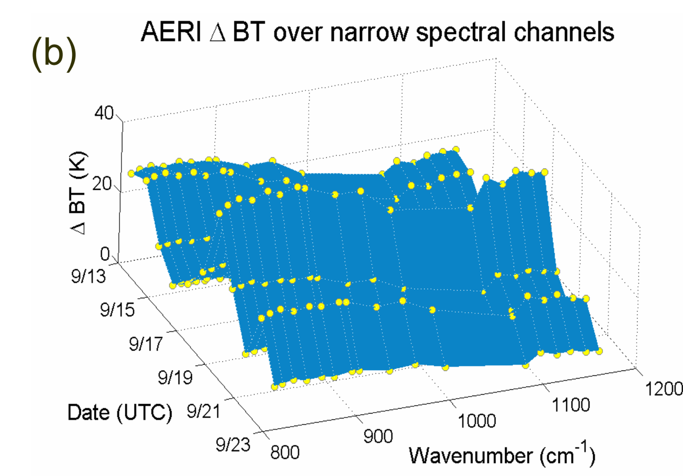

Fig. 2b. Daily averaged dust ΔBT from Sept 13[th]-23[rd] evaluated along AERI narrow spectral channels

I I I. Dust Size Shape & Composition

MAARCO in-situ data forms basis for dust models used in study. Size parameters inferred from aerodynamical particle sizer (APS 3321). Shape/composition to be determined by SEM/EDS analysis of filter data. Data/figures presented below provided by J. Reid. (Details of in-situ results to appear in upcoming UAE² special edition[3]).

Size (APS):

- Data collected from 8/11-9/30 with 1-hr time resolution
- Blue curve in Fig. 3(a) shows hourly common-mode (0.8-10μm) dust volume concentrations
  - Note several peak dust episodes (> 1σ = 200 μm³ cm⁻³)
- Red curve is proxy for pollution using APS channel 2 (0.542μm endpoint)
- Figs. 3(b)-3(d) give daily averaged size distributions for volume, surface area and number concentrations respectively. Each is normalized by the common-mode volume. Note shift in volume/area modes for each distribution indicative of potential composition change

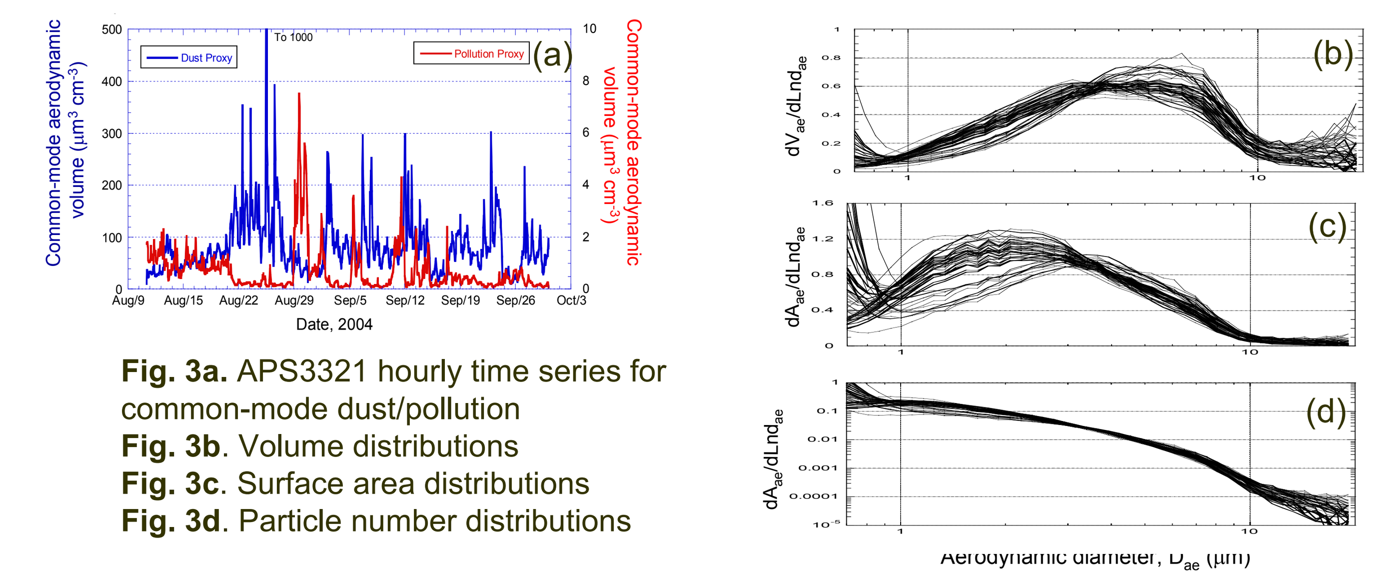

Fig. 3a. APS3321 hourly time series for common-mode dust/pollution
Fig. 3b. Volume distributions
Fig. 3c. Surface area distributions
Fig. 3d. Particle number distributions

Shape and Composition (filter)

- UAE² shape/composition data remains under analysis
- Data from past studies (PRIDE/ACE-ASIA) used to characterize these parameters for now
- Fig 3(e) is an electron micrograph (secondary electron) of dust during UAE²
- Table (1) shows common dust minerals. Pure/aggregated mixtures are investigated.

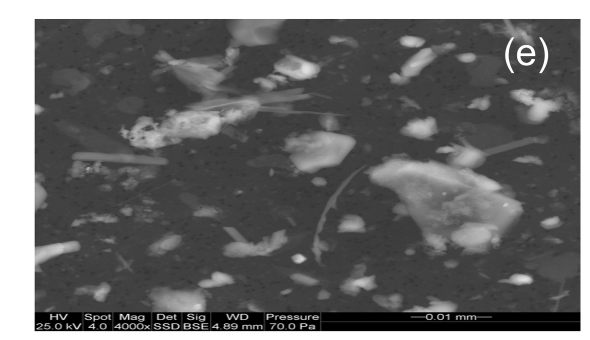

Fig. 3e. SEM image of dust particles (UAE²). Note angular shapes

Pure minerals	Aggregates (internal mixtures)
1. Amorphous quartz (Q)	9. Q + H (1-10%) mixture
2. Montmorillinite (M)	10. Clays + H (1-10%) mixtures
3. Kaolinite (K)	11. Q + Clays (50/ 50) mixture
4. Illite (I)	12. Q + Clays (75/ 25) mixture
5. Hematite (H)	13. CaCO3 + Clays (50/50) mixture
6. Calcium carbonate (CaCO3)	14. CaCO3 + Clays (75/25) mixture
7. Dolomite (D)	15. CaCO3 + Q (50/50) mixture
8. Gypsum (G)	16. CaCO3 + Q (75/25) mixture

Table 1. Common dust minerals

IV. Dust Single Scattering Properties

- Using size, shape and composition data, the single scattering properties of dust are determined (Fig. 4). Light scattering used in study include:
  - T-matrix (Mishchenko et al. 1994)[4] for spheroidal dust particles with aspect ratios between 1.4-1.9 (oblate)
  - Finite difference time domain (FDTD) (Yang et al. 2000)[5] for sharp-cornered particles having multiple facets (compact hexagons, tetrahedrons etc)
- mineral aggregates are evaluated using extended medium approximations (Maxwell-Garnet ; Bruggeman approximation) – Refer to section III, table 1.
- Optical properties are APS size integrated using equations (1-3) below

1.
$$<g> = \frac{\int_{a1}^{a2} g(a)\sigma_{scat}(a)n(a)\,da}{\int_{a1}^{a2} \sigma_{scat}(a)n(a)\,da}$$

2.
$$\beta_{ext} = \int_{a1}^{a2} \sigma_{ext}(a)n(a)\,da$$

$$\omega = \beta_{scat} / \beta_{ext} \quad 3.$$

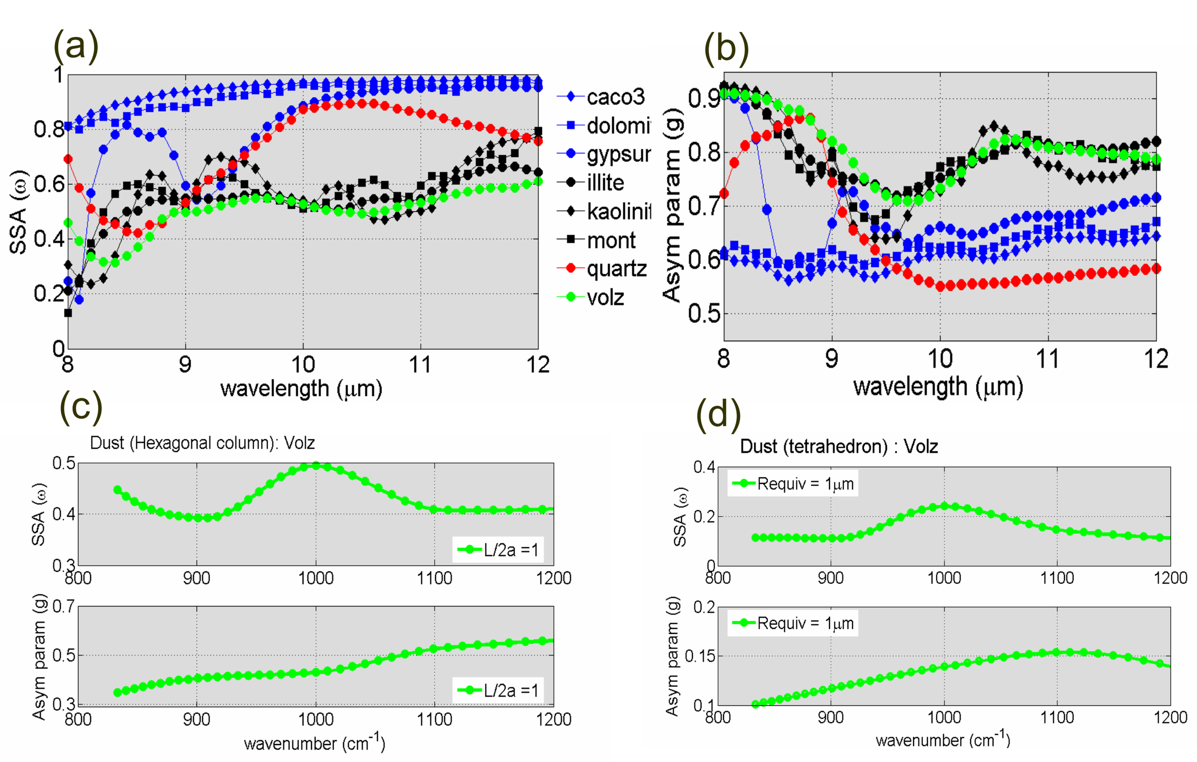

Fig. 4. Dust single scattering albedos (ω) and asymmetry parameters (g) for pure minerals and the Volz bulk mixture. Mineral classes are color-coded blue for carbonates, black for clays and red for silicate. Green represents the Volz Saharan dust model. Single scattering albedo and asymmetry parameter for oblate spheroids are given in (a) and (b) while the same for both hexagonal column and tetrahedron are given in (c) and (d)

V. Retrieval Methodology and Results

Methodology

- CHARTS RTM builds LUT of BT's across 17 AERI narrow spectral channels using developed dust models (section III) characterizing size, shape and composition
- BT's computed at AOT(10μm) for τ = 0.05, 0.2, 0.4, 0.6, 0.8 and R_{eff} = 0.8, 1.5 and 2.0μm
- Uses mid-latitude summer atmospheric profile.
- Points linearly interpolated to further resolve τ
- Temperature corrections applied to AERI spectra to account for T↑ during day
- Retrieval employs statistical optimization approach using Eq's 1 & 2 below for assumed composition

$$\chi^2 = \sum_{i=1}^{17} [\ln(\Delta BT^{i}_{calc}) - \ln(\Delta BT^{i}_{aeri})]^2 \quad (1)$$

$$\Delta BT = BT_{calc\,/\,aeri} - BT_{clear} \quad (2)$$

Results

- Shown below are retrieved AOT results for Sept 19[th] (Fig. 5a). Boxed region coincides with times of dust transit (see MPL image, Fig. 5b)
- Fig. 5c shows AERONET comparison with scaled AERI optical depths (0.55μm) corresponding to boxed region
- Fig. 5d shows aircraft temperature/relative humidity profiles over Al Ain area on Sept 19[th] between 12:07-12:17 UTC
- AERI scaling factor defined as extinction coefficient ratio [β_{ext}(0.55μm)/ β_{ext}(10.0μm)] which varies with size, shape and composition
- Spheroidal dust model composed of amorphous quartz was used
- Comparisons at other times on Sept 19[th] not as favorable most likely attributed to changing dust properties. This needs further investigation
- The success of AERONET comparisons strongly depends on choosing a reasonable composition model and AERI scaling factor a priori

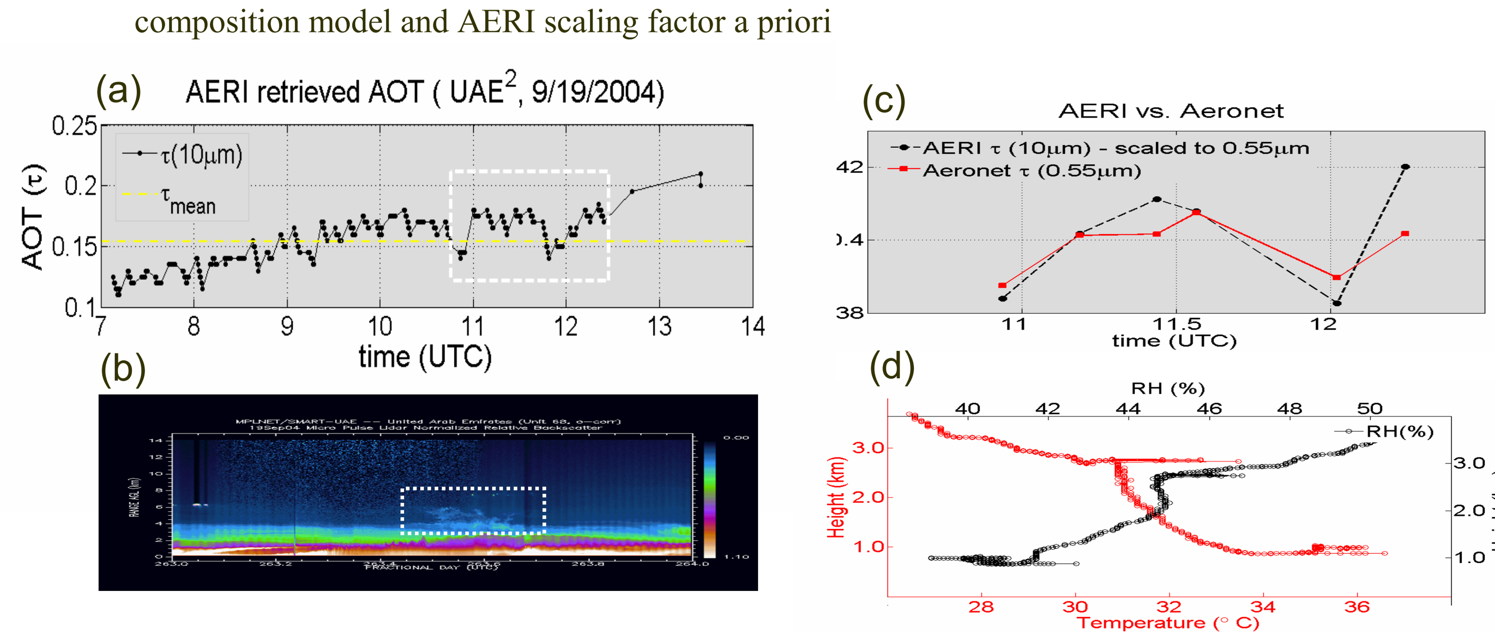

Fig. 5. (a) AERI retrieved optical depth ($\tau_{10\mu m}$) for Sept 19, 2004. Boxed region corresponds to times of dust transit. χ^2 summed over channels 11-17. (b) AERONET comparison with scaled AERI optical depths (0.55μm) corresponding to boxed region. (c) MPL image on same day showing dust in boxed region. (d) aircraft temperature/relative humidity profiles.

VI. Conclusion and Future Works

- UAE² provides unique dataset for improving our understanding of key dust properties in a region plagued by significant aerosol activity
- MAARCO in-situ data forms basis for constructing IR dust optical properties database. Prior field studies (PRIDE/ACE-ASIA) currently used for shape/mineralogy inputs to models
- Observed radiances from SMART AERI system used in conjunction with dust models to retrieve critical dust optical/microphysical parameters
  - IR optical depths (τ) retrieved from AERI data on Sept 19[th] were shown to agree reasonably well with AERONET
    - ❖ AERONET comparisons at other times are not as favorable due to changing dust properties. Retrieval success depends on choosing proper AERI scaling factor and composition model
  - 20 such retrievals will be performed to assess temporal variability of τ during study period
  - Using retrieved τ as input to Fu-Liou RTM, simulated longwave surface fluxes will be computed from which dust surface forcing can be determined
- Extensive FDTD calculations are required for irregularly shaped dust particles
- Sensitivity of single scattering properties to composition will be performed to exploit potential for mineralogy retrievals

VII. References

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